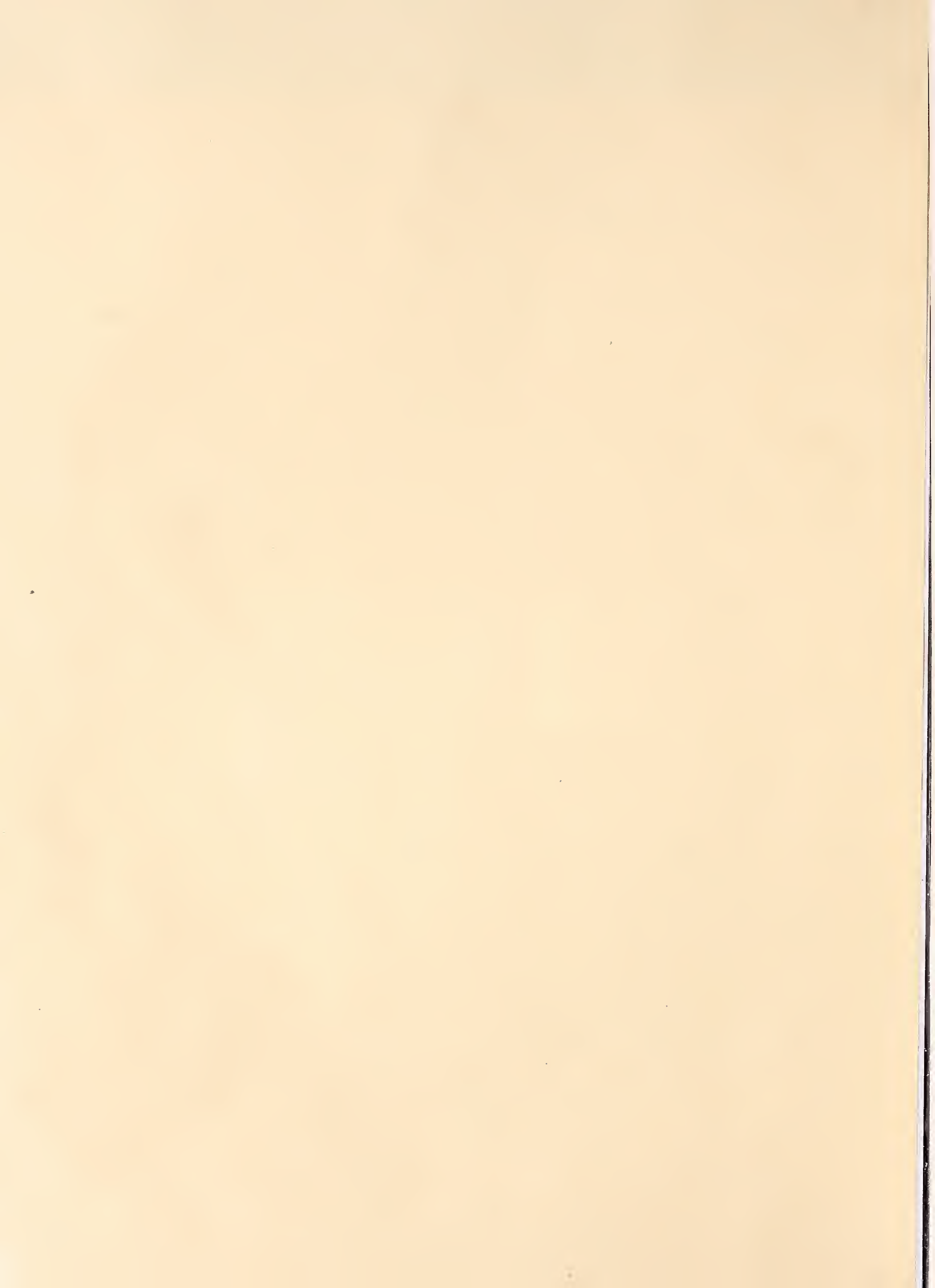# Historic, Archive Document

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Static Testing to Evaluate Airtanker Delivery Performance

**Aylmer D. Blakely, Charles W. George,
and Gregg M. Johnson**
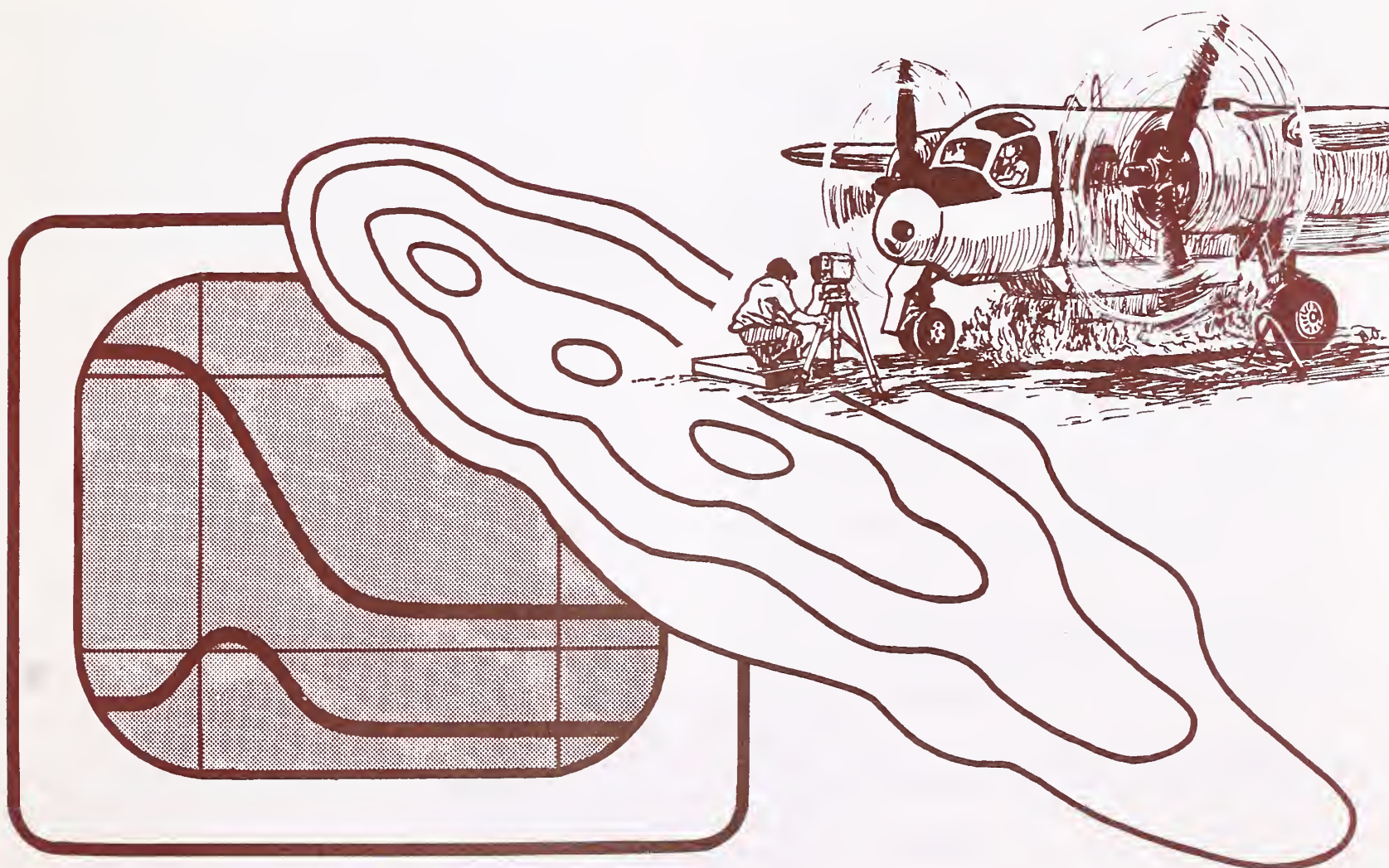
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RESEARCH SUMMARY

A number of airtanker performance guides have been developed by the USDA Forest Service and in cooperation with the Honeywell Corporation. These guides predict fire retardant ground distribution patterns resulting from various drop configurations that are possible with each tank and gating system. The guides were developed using a computer simulation model (PATSIM) and a number of inputs from a "static test" of the selected airtanker.

This report details the tank and gating system preparation and description needed to determine the static test matrix and for inclusion in the simulation. The data collection and analysis procedures are given in detail for reducing the data to a form that is usable for input to PATSIM.

Following procedures outlined in this report will make it possible to determine the expected performance of any airtanker for which a guide is unavailable by comparing its static test data with that of other airtankers for which guides have been prepared.

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Introduction

Innumerable retardant and water drops have been made on wildfires when neither the firefighters on the ground nor the airtanker pilot knew whether or not the retardant would get to the fire or what effect it would have. Consequently, numerous drop tests have been conducted to quantify the drop patterns of airtankers and retardants (USDA Forest Service 1955; Davis 1959; Storey and others 1959; Johansen and Shimmel 1967; Grigel 1970; George and Blakely 1973; George 1975; and Swanson and others 1978). In an attempt to mathematically simulate the air drop performance of aircraft, MacPherson (1968) developed a model that predicted idealized patterns based on tank geometry, tank door opening speed, aircraft speed, and drop height. The simulation model, however, was applicable only to aircraft making drops at relatively low drop speeds and heights (75 to 110 knots and 50 ft [15.2 m] to 100 ft [30.5 m] above ground). Utilizing the MacPherson model and actual drop pattern data available for several airtankers, Swanson and Helvig (1974) expanded the model to include the effects of the retardant physical properties on breakup and evaporation (thickened versus waterlike retardants) and refined the effects of drop height and airspeed. The model was altered to predict ground distribution patterns as well as summarize the results of incremental releases. Comparisons of predicted and actual performance at the various stages of model development indicated that acceptable estimates of patterns could be made by empirically tuning the model and inputting an actual flow rate of retardant from the tank (an adequate mathematical link between tank geometry and flow rate was not attained).

Swanson and others (1975, 1977), under contract to USDA Forest Service, utilized the pattern simulation model (PATSIM) with actual retardant flow rate data to develop the first user guides for several selected airtankers. The guides (Swanson and others 1977) are a summary of data for different drop conditions and configurations, compiled and simplified in graphs and tables than can help airtanker pilots, air attack specialists, and ground personnel use delivery systems most efficiently. A number of these guides have been prepared in notebook form as "Airtanker Performance Guides" and are presently in use.[1]

The purpose of this report is to outline procedures and provide instructions for collecting the flow rate data necessary for developing performance guides for selected airtankers.

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[1]U. S. Department of Agriculture, Forest Service. 1977. Airtanker performance guides. Report on file at the Northern Forest Fire Laboratory, Missoula, Mont.

Static Testing

A procedure for measuring the flow rate of retardant or water from an airtanker has been developed and termed "Static Testing." This involves the quantification of flow rates while the aircraft is parked, as opposed to tests conducted while the aircraft is in flight (fig. 1 shows an airtanker undergoing static testing). During the development of static test methods, water and retardant were dropped from the same tank and gating system while the aircraft was parked on the ramp and during flight. These tests indicated that no significant difference in the flow rates existed for water or retardant (thickened Phos-Chek XA or unthickened Fire-Trol 931-L) whether the aircraft was parked on the ramp or in flight, provided certain conditions were met. The necessary conditions included: (1) the aircraft being situated in a "near flight attitude" and (2) having similar tank door-opening speeds when the aircraft is in the static position and in flight (the door opening speed is related to the method of opening the doors and/or the power source for opening the doors, that is, using aircraft engine power, hydraulic or pneumatic pressure systems, or simply gravity). Accordingly, the flow rate data needed to predict airtanker performance using the pattern simulation program PATSIM can be collected by "static testing" the aircraft tank and gating

system with water as the retardant medium. Obtaining the flow rate data in this manner avoids the extra time and dollars necessary to conduct drop tests for determining airtanker performance. To determine the performance of a delivery system by in-flight testing, a large number of flights are necessary to vary the drop heights and speeds plus utilize all possible tank and gate drop combinations. Static test data, the computer, and the PATSIM simulation model make possible a thorough test series that can examine a wide range of velocities, drop heights, and retardant types in only a few days. The usual time needed for two or three persons to perform "static tests" on a single aircraft delivery system is 2 to 3 days, depending on its complexity.

Static test data is gathered with mechanical and/or electronic sensing devices placed within the tanks and on the tank doors. The primary parameter measured during static testing is the fluid flow history (rate of discharge) as it exits the tank. This is usually measured by monitoring floats that follow the upper surface of the fluid when the tank doors are opened.

Flow rate is the only parameter needed as a tank and gate system input to PATSIM. Other parameters such as door open angle (as a function of time) and tank venting (pressure) are measured to provide insight to the relative importance of system variables and as indicators for

Figure 1.—Static testing a California Division of Forestry S2F airtanker. Notice it was necessary to run the engines to obtain representative door opening times.

trouble shooting and determining the adequacy of data. For example, if inadequate venting exists, the float data will be inaccurate if a partial vacuum causes the fluid surface to slow or stop thereby affecting the float. Opening the doors with and without the engines running can determine whether or not the doors will open at the same rate during both static tests and in flight.

During static tests, initial results often indicate delivery system performance limitations or shortcomings. It is not uncommon for airtanker operators to respond to these test results and make on-site modifications during the tests to improve the performance of their tank and gate system. Although such action is desirable, it is important that such modifications be completed prior to collecting final static test/system performance data.

Procedures

The procedures for conducting static tests on airtanker delivery systems have been developed by experimentation. Many variations exist between tank and gate systems presently in the airtanker fleet, that is, door-opening and closing mechanisms, tank configuration, methods of venting, and so on. These variations often require modification of procedures and adapting available instrumentation.

Procedures have also been modified to be compatible with other static testing objectives. For example, in some instances it has been possible to collect the necessary data to develop airtanker performance guides while conducting an evaluation of a newly developed tank and gating system. To check mandatory design and/or performance criteria established by the Interagency Airtanker Board (appendix A) for new systems, much of the same data gathered during static testing is required. Consequently, the static test methods discussed here have been adopted for evaluation of new delivery systems.

The procedures outlined in this publication are intended to be fairly specific, yet provide the basis for an understanding of the relationship between primary variables while pointing out various external factors that may have a significant effect on the outcome of the tests. Because of the large number of variables and factors influencing static test results and tank and gate system performance, it is not practical or possible to establish a rigid, ordered static test procedure. The test matrix selected must be based on recognition of the primary influencing factors. The procedures have been divided into three major areas or tasks, and a discussion of each follows.

Tank and Gating System Preparation

Prior to conducting static tests, several questions and/or influencing factors must be considered and dealt with. The primary goal of the preparation is to assure that the performance of the tank and gating system under static conditions will be similar to its in-flight performance and that the test configuration and data collected will be accurate and reflect conditions existing during operational use. Primary considerations include the following:

Tank Integrity - Significant loss of fluid from the tank, either internal or external, can influence the rate of change of the fluid surface (which correlates to flow rate) when a compartment release is made. External leaks from a compartment or tank are easily detected visually, but internal leaks are more obscure. Flow to or from a compartment that is adjacent to a compartment being released (that is, through leaks in the tank seams, unclosed cross flow openings or flapper doors, or loading manifolds) can significantly affect the fluid level and flow rate calculations. (Such leaks can also adversely affect operational performance; for example, poorly sealed cross flow doors installed for loading purposes can result in intercompartmental flow after partial drops. As a result, pilots could unknowingly return to base with part of the retardant load.) Therefore, leaking or cross flow should be minimized to increase the accuracy of the fluid level history during a release. A leak is significant if it causes the fluid level in a measured or adjacent tank to drop more than one-half inch (12.7 mm) during preparation for the drop or during the drop (noted by observing the fluid level in the measured or adjacent tank).

Tank Configuration/Sequence - The normal operational drop configurations or sequences should be determined since the number of drop combinations will dictate the static test matrix chosen. The most desirable drop configurations as outlined in the mandatory tank and gate criteria (appendix A) and by Swanson and Luedecke (1978) ("Tank Design Guide") should be considered at this point. Minor electrical changes in the tank and gating intervalometer system can sometimes be made to improve drop pattern performance and make the system conform to new requirements. If such changes are anticipated, it is best to incorporate them prior to static testing since they will alter performance and can, depending on the magnitude of the change, invalidate the data and the performance guide being developed.

In-Flight Aircraft Attitude - The attitude of the aircraft tank and gating system can affect volume distribution in compartments within the tank (especially long tanks) and affect the accuracy of measurements of fluid flow rate from the tank. This will depend on the instrumentation used to monitor the liquid level and its location in the compartment. Therefore, it is necessary to estimate the in-flight attitude and determine if it is significantly different when the aircraft is in a parked position (the largest differences usually exist for aircraft which sit on a tail wheel). This adjustment is often subjective, but usually the airtanker is positioned with the tank bottom approximately level. Wheel struts may be adjusted or a tail jack used to elevate the aircraft tail (for example, the tail of B-17 aircraft must be raised 3 ft [0.91 m] to 4 ft [1.22 m] as shown in fig. 2).

Describing the Tank and Gating System

In addition to preparing the tank and gating system for static testing and after preliminary checks are completed, several measurements must be made to determine which compartments must be instrumented. To collect sufficient data to build an accurate performance guide, it is necessary to instrument and test all tank compartments, singles or combinations, **that have different flow rates.** Usually, it will not be necessary to static test every compartment in a tank and gate system. Wasted time and effort will be avoided if only compartments having significantly different performance are tested. A good description of the tank and gate system will assist in determining which compartments or conditions can be expected to yield different performance, that is, flow rates.

There are several parameters that should be quantified and considered when looking for probable differences in compartment flow rates; compartment size and geometry, vent access, and door opening rates and angles. The description of the tank and gating system should include: (1) door opening area measurements, (2) compartment dimensions, (3) compartment volumes, and (4) marks at water levels for different approved loads/down loads (head height). (The tank geometry and dimensions are used in developing an algorithm to determine the volume discharged at any given time during the drop from which flow rate is calculated.) The spatial arrangement of the compartments is noted in order to provide a "near scale" drawing of the tank and gating system (for inclusion in the performance guide [as shown in fig. 3]). The spatial arrangement can affect drop patterns, but the Pattern Simulation Model presently does not incorporate a mechanism for handling this variable, although it may be possible with future refinements. "Static Testing Information Checklist and Data Sheet" (appendix B) is a guide to assist in gathering various tank and gating system data, including general tank dimensions and geometry.
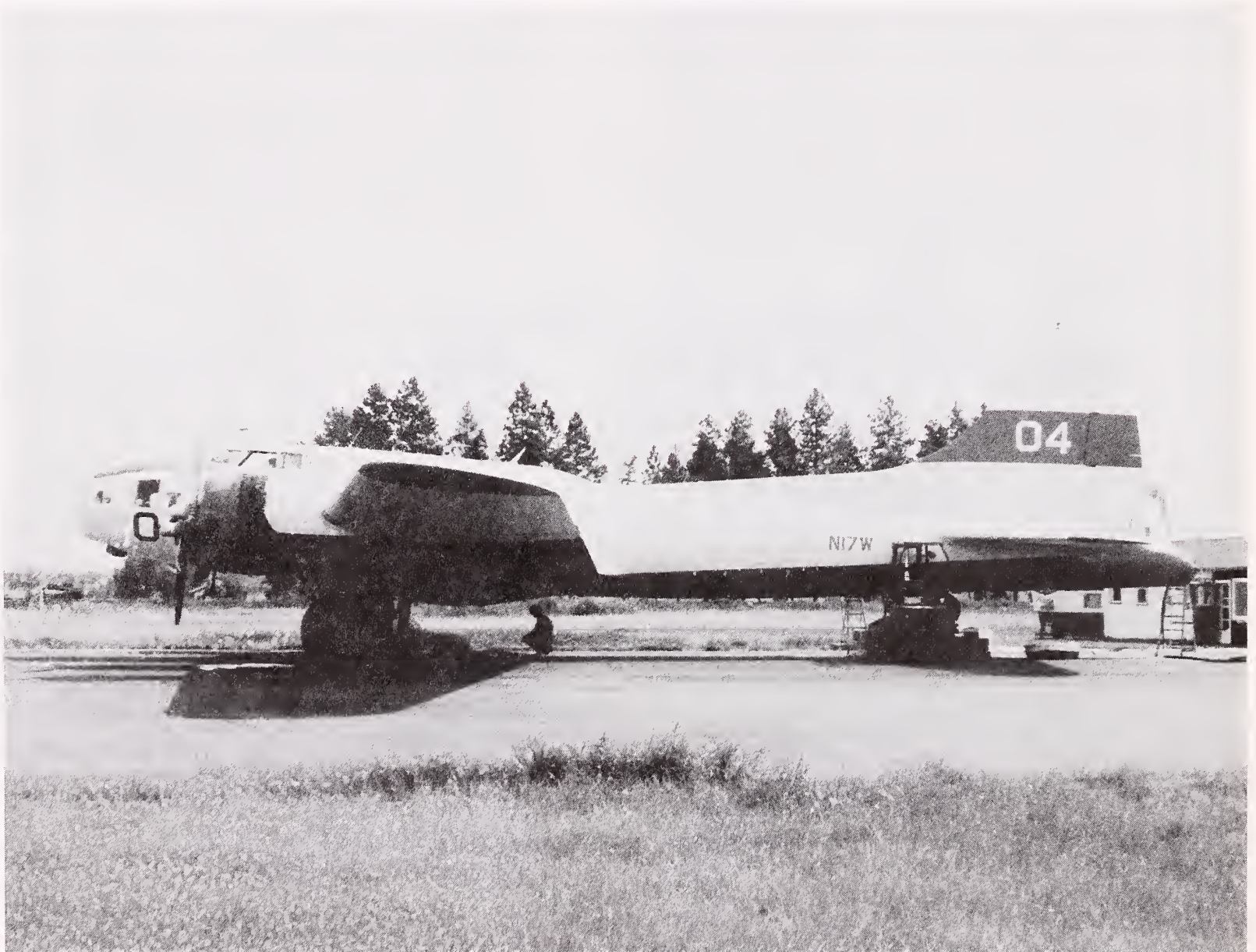

Figure 2.—Raising the tail of a B-17 to establish a "near-flight attitude" for static testing.

Figure 3.—Dimensions, volumes, and spatial arrangement of compartments of Hawkins and Powers tanked PB4Y2 airtanker.

Vent access should be measured and examined to determine: (1) the door-opening area to vent area ratios for each individual compartment, (2) situations where vent access routes may be shared by two or more compartments, reducing the available venting when multiple releases are made, and (3) if shared vent access is blocked by water when compartments are full.

Door travel should be checked by appropriate means to detect the variations in rates or angles. All doors should be opened in all possible drop sequences (singles, doubles, etc.) with and without water and with and without engine(s) running to determine: (1) the normal door opening sequences, (2) if all doors are opening and closing properly, (3) the door angles when fully open for all possible drop configurations, and (4) if differences in door opening times and angles exist.

Numerous factors can influence the time required for an individual door to open and the angle of opening. If doors do not open at a constant rate, then the opening areas as a function of time may not be linear. Some factors that may cause different door opening rates or angles on a tank and gate system are: (1) weight of and/or lubrication by water or retardant, (2) differences in the diameter and length of hydraulic lines serving each door, (3) insufficient accumulator, pump, or hydraulic line capacity for the number of compartments released simultaneously or in quick sequence, and (4) variable aircraft power source (that is, door opening system power is supplied by hydraulic pressure produced by aircraft engine pumps or hydraulic or pneumatic pumps are powered by aircraft batteries.) These differences are important in establishing a procedure that will assure door opening rates are the same in-flight as under nonflight static test conditions. The differences can usually be prevented by running an aircraft engine or engines or by using an adequate ground power unit. (Consideration of this factor should always be a part of conducting static tests.)

Determining the static test matrix

As previously mentioned, it is usually not necessary to perform complete static tests on every compartment of a tank and gate system. If compartments have similar geometries, door area, opening rates, and venting, the flow rates will not be significantly different. The problem, however, is to identify the situations where minor to major differences result in different performance and actual flow rate measurements become necessary.

Preparing a table of tank compartment characteristics will help to identify which compartments will require flow rate measurements. In all cases, it is necessary to quantify the door opening time and angle for each compartment and drop combination or sequence. Table 1 provides a description of various tank characteristics prepared in order to plan a static test matrix. Data as provided in table 1 can then be used to determine which compartments will represent other compartments with similar performance. When two or more compartments are chosen for testing, they should be in separate groups of multiple-compartment releases. The procedure can be illustrated using the Hawkins and Powers tank in a Super PB4Y2 described in table 1 (data from the Airtanker Performance Guide).

The apparent differences are compartment geometry, door opening times, and volume. Either compartment 1 or 2 should be tested because of the different geometry (there may be complications caused by loading, fill gages, access for placing instruments, etc., that can dictate choosing other compartments for testing). The average volume of compartments 3 through 8 is 271 gallons (1 026 liters); therefore, compartment 6 could be representative for this volume. Compartment 6 has a 1.4 sec door-opening time that could be representative for that parameter. Door sequences are: SINGLES - 1, 7, 3, 5, 2, 8, 4, 6; DOUBLES - 1 and 7, 3 and 5, 2 and 8, 4 and 6; and FOURS - 1, 3, 5, 7 and 2, 4, 6, 8. Therefore, compartments 6 and 1 apparently could represent all variables of different compartments.

Table 1.—PB4Y2 tank and gate system physical description and characteristics

Compartment	Door size	Compartment dimension	Door opening Times	Door opening Angles	Head height	Vent area	Vent ratio (door to vent area)	Metered volume[1]	Other
	·······Inches········		Seconds	Degrees	Inches	(Ft²)		Gallons	
	L × W	L × W × H							
1	46.5 × 16.5	50 × 19 × 63	1.5	68	52	1.27	4.4:1	258	Notch in front
2	46.5 × 16.5	50 × 19 × 63	1.8	68	52	1.28	4.4:1	246	Notch in front
3	46.5 × 16.5	50 × 19 × 63	1.7	68	52	1.38	4.4:1	275	
4	46.5 × 16.5	50 × 19 × 63	1.5	68	52	1.36	4.4:1	278	
5	46.5 × 16.5	50 × 19 × 63	1.5	68	52	1.38	4.4:1	285	
6	46.5 × 16.5	50 × 19 × 63	1.4	68	52	1.35	4.4:1	268	
7	46.5 × 16.5	50 × 19 × 63	1.5	68	52	1.35	4.4:1	259	
8	46.5 × 16.5	50 × 19 × 63	1.3	68	52	1.36	4.4:1	261	

[1]Variations in volume were caused by differences in tank configurations and slight differences in the location of the fill-level indicator switches.

Data Acquisition

Requirements

The data collected for calculating the necessary inputs to the pattern simulation program (PATSIM) include: fluid level versus time, door-open angle versus time, internal tank pressure versus time, tank geometry (tank dimensions), door geometry, tank volume, and starting and ending positions of the float and doors. For all airtankers tested so far, the time required to open the doors and evacuate tanks has varied between 0.2 sec and nearly 5 sec. In order to accurately define the data, the readability of the time base should be within 2.0 percent of the total time required for the event. Door-opening angle measurements should be accurate to 1 degree, starting and ending fluid levels to one-eighth inch (3.2 mm) and pressure to 0.1 psi (70.3 kg/m²). Measurements of tank and door geometry to one-eighth inch (3.2 mm) and tank volume metered to within 5 gallons (18.9 liters) have proven adequate.

Methods

Three of the data measurements (fluid level, door open angle, and internal tank pressure) are recorded against time by using a time base recorder. High-speed strip chart recorders, tape recorders, oscilloscopes with camera, and electronic data acquisition systems have all been used. Any recording device should have at least six channels of input in order to provide measurements on more than one compartment during each separate release. The fluid level measurement is made using a float, horizontally stabilized by a guidewire, that rides on the surface of the fluid as it exits the compartment. The float is connected to a linear output potentiometer by a cord and pully arrangement (fig. 4), and the change in voltage is recorded as the float follows the dropping fluid surface. Since the voltage change is proportional to the distance traveled, the position of the float (or fluid level) at any given time can be calculated by using the measurements of float starting and ending positions. The mass of the cord and pulley arrangement must be kept as small as possible to avoid inertial effects.

Door-opening rate measurements are made with a potentiometer that is directly connected to an actuating arm that rides in a bracket taped to the door. Pressure measurements are made using a commercially available transducer that produces a DC signal proportional to pressure. The transducer is mounted at a location on the tank free of influence from other pressure sources, such as air drafts from the vent.

The full door-open angle is used primarily as a parameter to compare geometrically similar compartments at the start of testing. If "door open" times are the same for geometrically identical compartments, flow rates will be the same, therefore, only one of the identical compartments need be tested. Door times are also compared for the same compartment when different drop configurations are tested. (That is, compare the door times for a single compartment drop with times for a salvo drop. If they are the same, flow rates for these configurations should be identical.) When replicate drops have different flow rates, an examination of the associated door times may explain the difference.

Metering water into the tank assures the proper water level for a given load size at the start of testing. Once this level has been marked, each subsequent filling
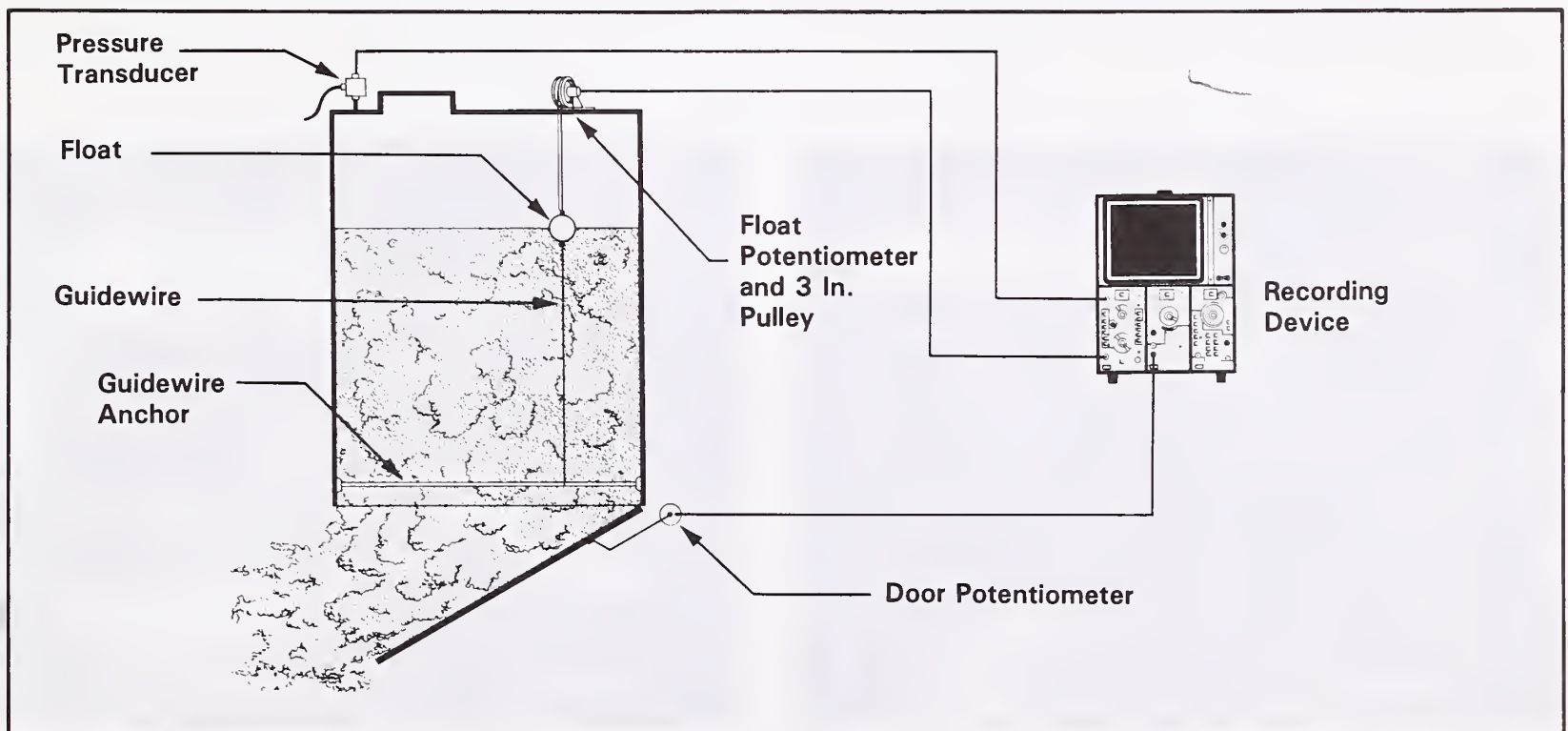

Figure 4.—Schematic of instrumentation.

should be within one-eighth inch (3.2 mm) of the mark for flow-rate accuracy.

Pressure measurements are made to identify drops when inadequate venting causes the dropping upper surface of the fluid to slow or stop and to incorrectly represent flow out of the tank. When the negative pressure is high enough, the dropping upper surface of the fluid is totally stopped while fluid continues to flow from the bottom of the tank (fig. 5). In this case, flow rate must be synthesized. (A method for synthesizing was developed by Honeywell Corporation [Swanson and others 1975] and is explained in detail.)

Data Processing

Data from the recording device or devices are digitized (unnecessary if an electronic data reduction system is used) by using an electronic system (fig. 6) and are stored on magnetic tape for reduction by using a desk top microcomputer. For most tests, about 30 digitized points are sufficient to define individual data traces. The points are chosen so that there is a relatively higher density of points over sharply curved portions of the trace. The digitized data are converted to volume discharged from the tank at a given time, flow rate, door opening area, door open angle, and tank internal pressure.

Since the door and float transducers produce linear voltage changes corresponding to float position and door-open angle, the door angle or float position at any given time may be calculated by:

$$\frac{F}{T} R = P$$

where F = total float travel (inches/centimeters), or maximum door-open angle (degree).
T = total trace displacement (in recorder units).
R = recorder trace displacement at time t.
P = float position or door-open angle at time t.

The pressure transducer is factory calibrated; therefore, actual pressure is found by applying a calibration constant.

To convert the position of the float in the compartment to volume discharged, an algorithm is derived, based on compartment geometry, that yields the volume remaining in the compartment at any float position. The compartment is divided into sections based on its geometry, and these sections are summed for the complete algorithm (fig. 7). The triangular ends are added to or subtracted from the rectangular portion for each section.

$$(W_i \times L_i \times D_i \times C) \pm 1/2\,(WT_i \times L_i \times D_i \times C)$$

(If both sides have triangular areas, the second term (1/2 $WT_i \times L_i \times D_i \times C$) is doubled.)

where WT_i = width of the base of the triangular portion in section i.

If θ_i = the angle between the rectangular and the triangular portion $WT_i = D_i \tan\theta$

Volume = $W_i \times L_i \times D_i \times C \pm 1/2\,(D_i^2 \times L_i \times \tan\theta \times C)$

or for any float position Dt_i

Volume = $Dt_i\,(W_i \times L_i \pm Dt_i^2\, \dfrac{(L_i \times \tan\theta \times C)}{2}$

Volume = $Dt_i\left[(W_i \times L_i \times C) \pm (Dt_i\, \dfrac{(L_i \times \tan\theta \times C)}{2})\right]$

An example for Central Air Service DC-7 tanker 110 is given in appendix C.
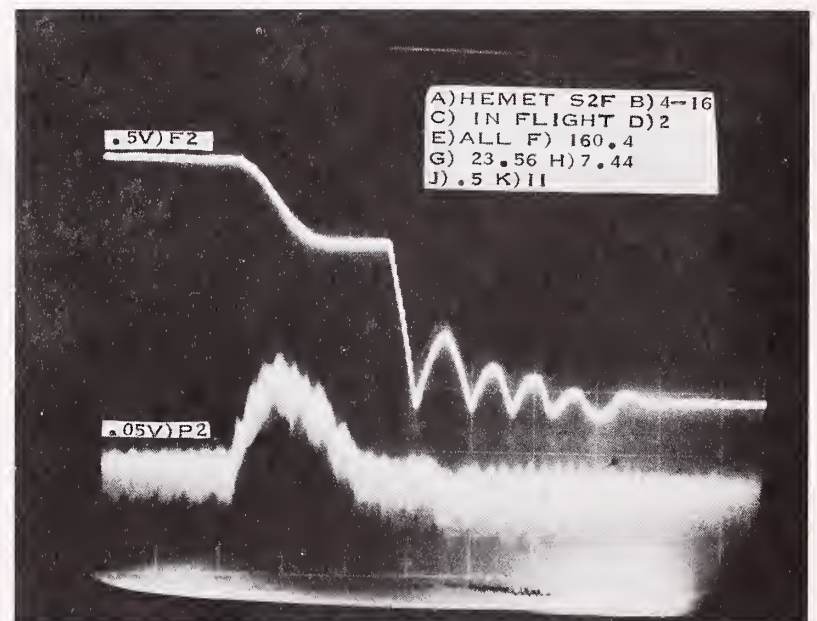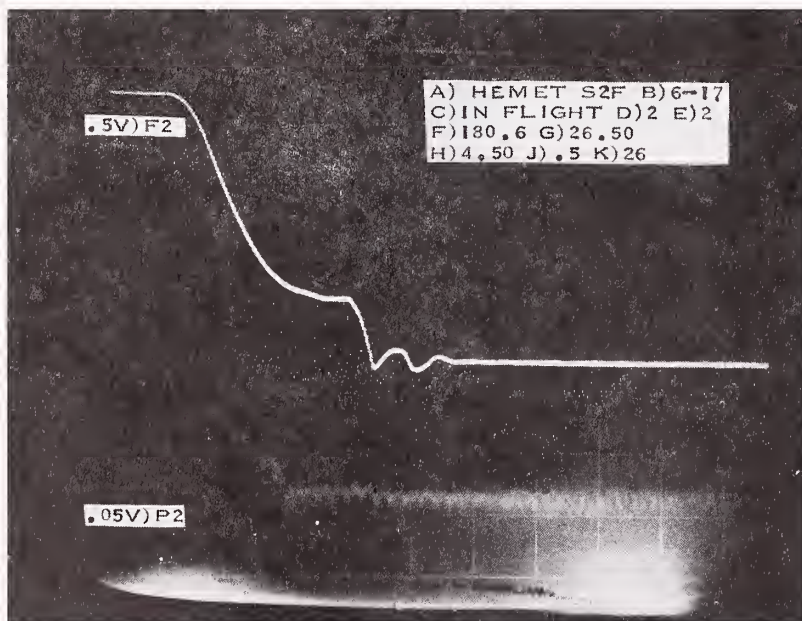

Figure 5.—Oscilloscope traces of the static test of an undervented tank. The single-compartment drop (left) and four-compartment drop (right) share the same venting. The four-compartment drop requires four times as much air, generating much greater negative pressures.

Figure 6.—Digitizing a polaroid photo of a static test oscilloscope trace.

For a rectangular cross section
Volume = $W_i \times L_i \times D_i \times C$
where W_i = width of section i
L_i = length of section i
D_i = depth of section i
C = constant for conversion to gallons

Volume in section i at any float position Dt_i
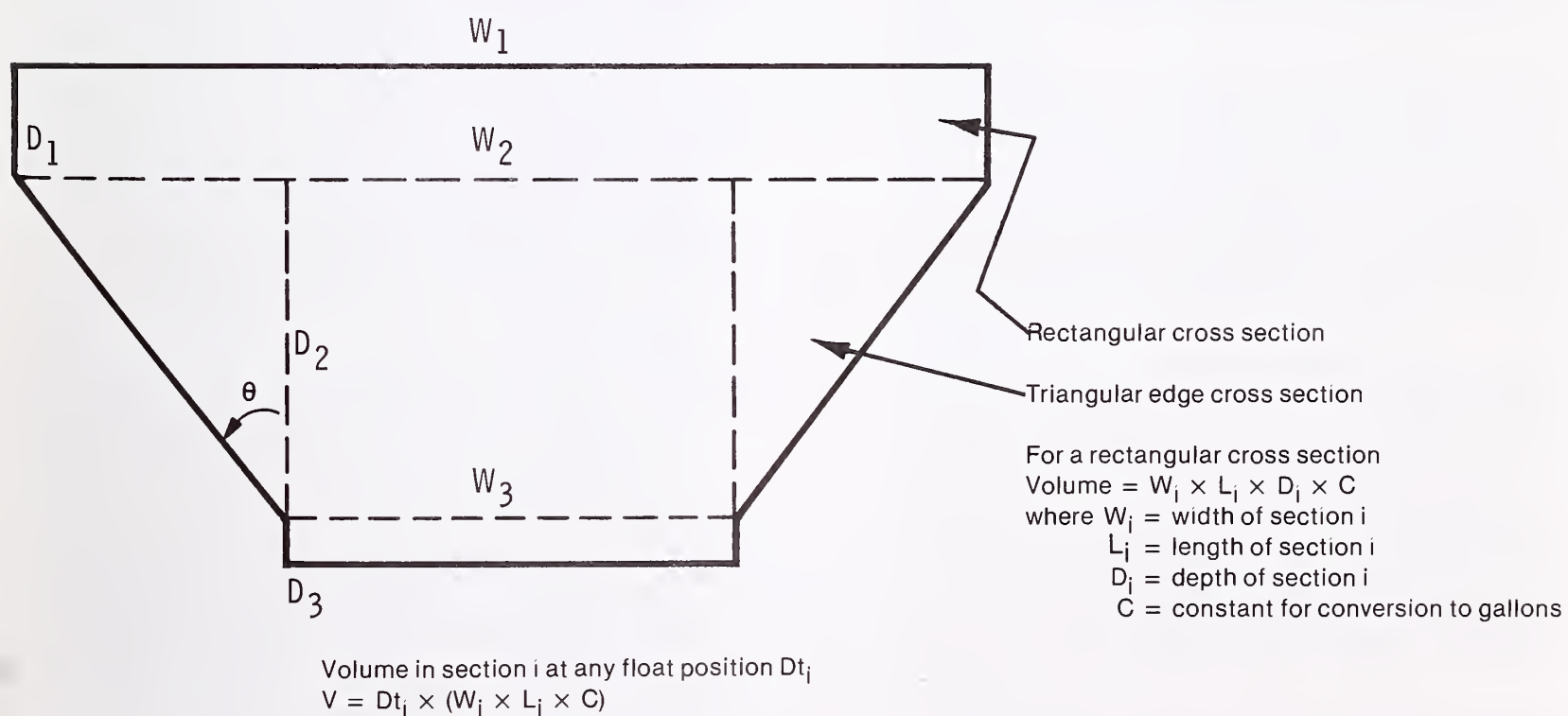$V = Dt_i \times (W_i \times L_i \times C)$

Figure 7.--Cross section of tank showing measurements
for volume-flow-level calculations.

Pattern Simulation

The main input to simulate a drop pattern using the PATSIM program is a table of volumes discharged versus time for the drop configuration being tested. Other inputs include drop height, drop speed, total volume dropped, retardant type (waterlike or gum-thickened), and the number of compartments dropped. For each PATSIM run, several different drop heights, airspeeds, etc., may be input to produce a set of simulated patterns covering a matrix of drop configurations. The details of operating PATSIM are published in reports (Swanson and others 1975, 1977) on the development of user guidelines for selected retardant aircraft. An instruction manual for utilizing user guides has been developed (Swanson and others 1976) and various "airtanker performance guides" have been prepared.[2]

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[2]Airtanker performance guides that have been prepared are on file and are available from the Northern Forest Fire Laboratory, Drawer G, Missoula, MT 59806.

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APPENDIX A
INTERAGENCY AIRTANKER BOARD
MANDATORY CRITERIA FOR
NEW TANK AND GATING SYSTEMS

I. GENERAL

a. Requirement:
All tank systems shall not leak when loaded with water to a volume equivalent to the volume of retardant at the maximum certified retardant load. Following initial loading, the tank system shall be capable of sitting loaded as described above for a minimum of 1 week without leaking more than 3-1/2 gal (1/2 gal/24 h).

Procedure:
Load tank to certified amount using approved meter or weighing system. Determine the leakage occurring over a 14-h period (usually this will be overnight). The leakage volume for the 14-h period shall not exceed 0.3 gal.

b. Requirement:
All tanks must be equipped with an independently controlled and operated emergency dump system enabling the pilot to drop his complete load in less than 6 sec. No one major malfunction can render both the operating and emergency system inoperative. The primary dump switch must be positioned within easy reach of the pilot and co-pilot while strapped in their respective seats.

Procedure:
The emergency dump system must be operative when activated using the primary emergency dump switch(es) as described above.

c. Requirement:
All tanks shall have the capability of being off-loaded through standard 3-inch Kamlock or equal couplers. Upon offloading, the amount of retardant remaining in the tank shall be less than 100 gal.

Procedure:
The operator must demonstrate the offload capability by connecting a 3-inch diameter hose and offload water from the tank.

d. Requirement:
All tank doors must be closable in flight.

Procedure:
Doors will be operative under static conditions. Flight tests will be required only if there is reason to question the operative ability of the door system during flight.

e. Requirement:
All retardant tanks shall be capable of being filled in conformity with the certified retardant load through 3-inch diameter single or dual Kamlock fittings, on either side of the aircraft or from the tail, at an average fill rate of no less than 500 gal/min. There should be sufficient crossflows so that the retardant will be level in all compartments within 30 sec after the pump is stopped. No compartment should fill faster than others such that retardant overflows from the tank (other than level indicator holes) before the certified volume is reached.

Procedure:
Tanks will be filled to the certified limit at 500 gal/minute and checked for even fill levels in each tank compartment.

f. Requirement:
Compartments sequenced individually in the normal drop configuration shall be constructed so as to eliminate leakage from one compartment to the other when one of the compartments has been evacuated.

Procedure:
All compartments will be filled to the level for a maximum certified load. Individual compartments will be manually activated in their normal sequence, checking each of the evacuated compartments for leaks from adjoining tanks. Leakage from adjoining tanks producing a combined flow of greater than 1 gal/min will constitute leakage.

g. Requirement:
Opening of the doors shall be through primary switches or a mechanism located on the control yoke or throttle/trim quadrant.

Procedure:
The activating switches will be checked visually as the tank and gate system is operated for static test drops.

II. VENTING

a. Requirement:
Vents shall be constructed so as no retardant leakage or slosh-over will occur during taxiing or takeoff.

Procedure:
A visual check and measurements will be made of vent construction, and the height of the retardant in a full tank will be checked for distance below vent outlets. If clearance or vent door construction is questionable, the aircraft will be taxied when loaded at the maximum certified load and observations for slosh-over or leakage made.

b. Requirement:
The vent area for any compartment or tank shall be such that when the retardant is released from any given compartment or combination of compartments, resulting negative pressures do not create a "coke-bottling" effect causing nonuniform and turbulent flow. A door area to vent area for any compartment or drop combination employed shall not be greater than 10:1 or shall show that in flight negative pressure does not exceed 0.25 lb/in².

Procedure:
Negative pressure will be checked with a pressure transducer during static test drops. Door opening and vent areas will be measured and the vent to door area ratio calculated.

III. INTERVALOMETER

Requirement:

Sequencing of all doors shall be done with an intervalometer capable of sequencing doors at intervals continuously variable. (Sequencing single or 2, 4, 6, 8 compartment combinations.) Reproducibility and accuracy shall be within ± 0.1 seconds.

Procedure:

All door or drop combinations possible with the existing system will be monitored during static tests. Reproducibility and accuracy of timers will be checked with an oscilloscope, recorder, or other calibrated timing device.

IV. COMPARTMENT SIZE

Requirement:

1. Individual compartments shall not be less than 200 gal in size.
2. Individual compartments shall not be larger than 600 gal in size unless the gating system allows for reproducible control of the retardant flow rate of the > 600 gal by another method such as a pilot selectable dual door opening rate or a trail door (door of smaller size providing a lower flow rate).

Procedure:

Compartment capacity will be accurately metered while the airtanker is parked in a normal loading attitude. Existing marked fill levels will be checked and new ones permanently marked outside and inside the tanks when possible.

V. MULTIPLE COMPARTMENT DROPS

Requirement:

For drop combinations where more than one drop is made simultaneously, the rules given below shall be followed unless the drop configuration results in a weight distribution which causes the center of gravity to be outside the acceptable flight envelope.

1. When two or more compartments are dropped simultaneously (nonsalvo) and a choice of dropping forward and aft compartments, versus side-by-side compartments, is possible, the forward-aft combinations shall be employed (fig. 8).
2. Forward and aft compartments dropped simultaneously shall be in line with one another (fig. 8).
3. Side-by-side compartments dropped simultaneously shall be oriented in a manner to minimize separation (fig. 8).

Procedure:

All compartment drop combinations will be checked visually during static test drops.

VI. FLOW RATE

Requirement:

The flow rate of retardant from a compartment or compartments is the primary parameter controlling the ground distribution pattern. The required retardant concentration on the ground varies be-

tween 0.5 and 6 + gal/100 ft² depending on the fuel, weather, fire characteristics, etc. The concentration adequate for most fires and conditions is between 1 and 4 gal/100 ft².

The average flow rate for each load size/drop combination will be within a specified flow rate range. The acceptable range defined by minimum and maximum flow rates will be determined from the following equations, except for continuous flow trail systems where the minimum acceptable average flow has been set at 50 gal/sec. The acceptable flow rate range for selected sizes is given in table 2.

$$\text{Minimum average flow rate (gal/sec)} = \frac{DS}{2.03}$$

Maximum average flow rate (gal/sec) =

$$\frac{DS}{0.42939 + 0.0000299039DS}$$

where DS = drop size in gallons.

Procedure:

Flow rates will be measured by monitoring floats which follow the top surface of the water when tank doors are opened. Floats will be monitored for all normal drop combinations, and flow rates will be calculated using a computer programed algorithm which combines float travel distance and time with tank geometry.

VII. DOORS

Requirement:

The door size, shape, and opening speed are all parameters which can influence the retardant flow rate from a tank. Many combinations of these parameters may provide acceptable flow rates as specified in item VI. The most desirable combination, however, should minimize the fluid frontal area, not significantly deflect the fluid, while providing this flow rate. Thus, generally a long, narrow tank versus a square tank, with a fast-opening door, will be preferable.

The door, when fully opened, does not restrict or deflect the flow of retardant from the tank. When multiple parallel doors exist, they should be hinged open inward so that all retardant will be deflected toward the center line of the tank. This will prevent simultaneous compartment drops from being deflected in opposite directions.

Procedure:

Door-opening rates will be monitored using a potentiometer that is fastened to the tank and in line with the door hinge. A wiper arm makes contact with the door and is connected to the shaft of the potentiometer. Door angle versus time is transmitted to a recorder placed nearby. The measured door-opening times are used as indicators in identifying problems in flow rate (item VI) and sequencing (intervalometer, item III).

Undesirable

Desirable

Undesirable

Desirable
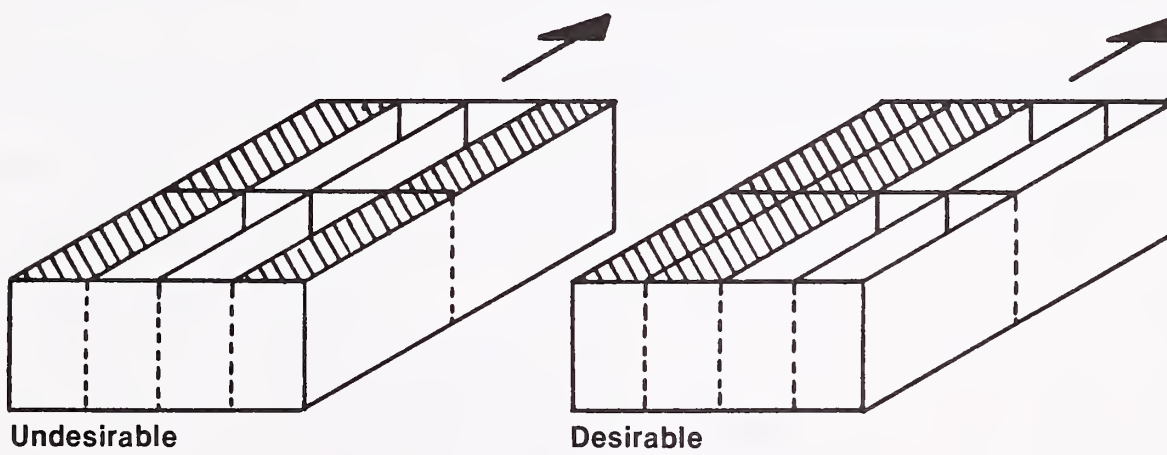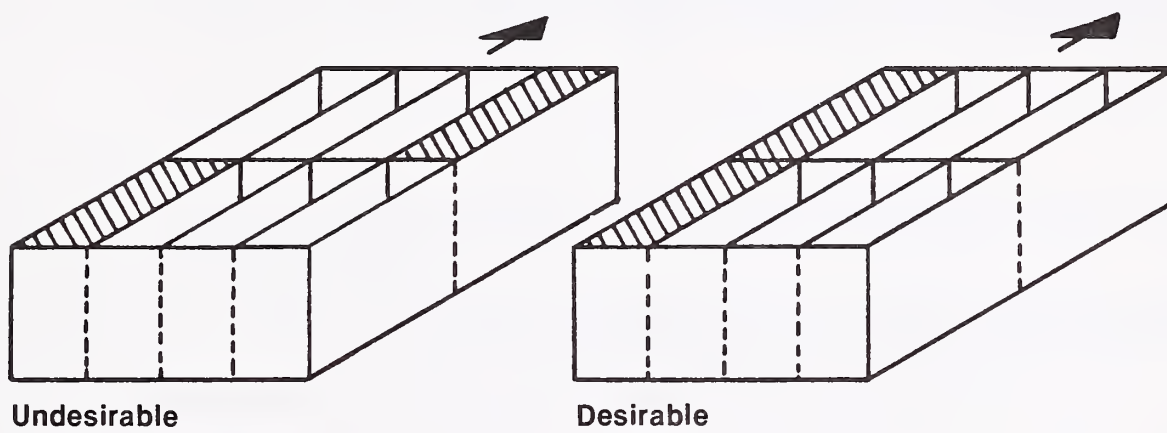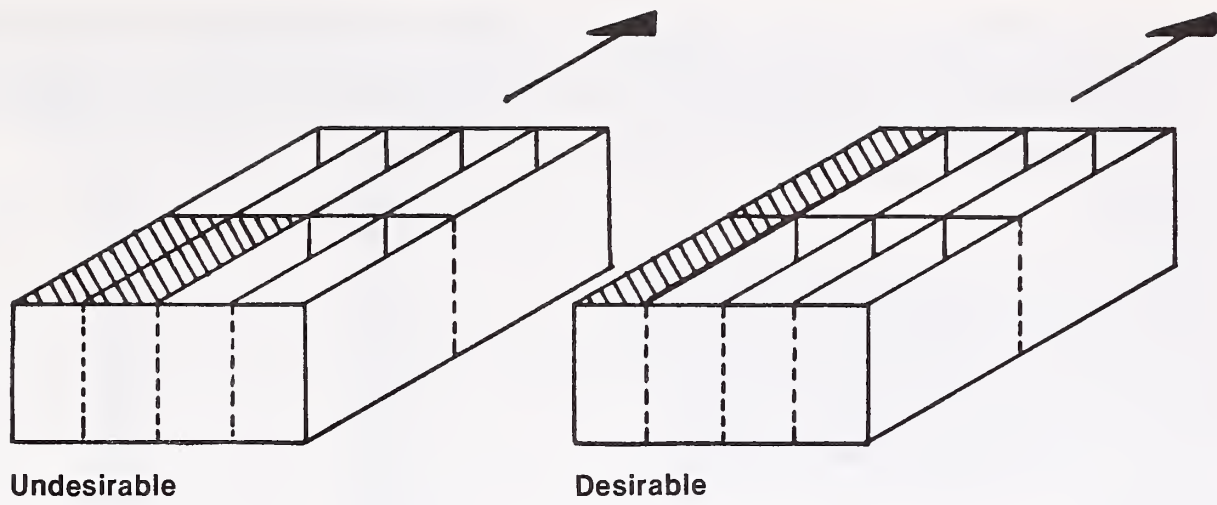
Undesirable

Desirable

Figure 8.--Rules of configuration for multiple compartment drops.

Deflection of fluid exiting the tank will be visually checked and recommendations will be made for correcting if the deflection is caused by door-opening times or structural configuration that can be corrected by minor modifications.

VIII. TANK FILL-GAGE

Requirement:

A positive-level gage or indicator shall be provided that shows when each compartment is filled to the certified load limit, or when each compartment is at predetermined partial load points if reduced loads are used. The gage or indicator shall be readily visible to the loading crew at the loading points and the tank capacity of each loading level clearly marked.

Procedure:

Fill-level gages are checked by metering accurate volumes of water while the aircraft is in its normal filling attitude. Permanent markers placed to indicate the certified load limit levels will be evaluated.

Table 2.—Acceptable flow-rate range for selected drop sizes.

| Drop size	Average flow rate	
Gallons	Minimum gal/sec	Maximum gal/sec
200	98	445
250	123	550
300	148	653
350	172	754
500	246	1,044
1000	493	1,892
1200	591	2,189
1500	739	2,595
2000	985	3,187
2400	1,182	3,598
2800	1,379	3,962
3000	1,478	4,129

APPENDIX B — STATIC TESTING INFORMATION CHECKLIST AND DATA SHEET

1. Operator _____

2. Designer and/or Fabricator _____

3. Aircraft Type _____

4. Airtanker ID: Tanker #_____; N_____; S/N_____

5. FAA Certified Maximum _____ Lbs.; _____ Gal.

6. Contract Volume(s) _____; _____; _____; _____; _____; _____

7. ID Number and Volume of each compartment: _____; _____; _____; _____;
   _____; _____; _____; _____

8. Compartment Combinations for Multiple and Sequence Drops:
   Doubles _____; Triples _____; Fours _____; Sixes _____; Eights _____;
   Other _____; _____; _____;
   Trail Sequence _____

9. Describe Door System: *

10. Describe Tank: * Sketch and label all dimensions so that a scale line drawing may be made (side and end views). This information will be used to calculate algorithm.

11. Describe impediments to flow: * (should include interior tank bracing, door operating mechanism, baffles, etc.)

12. Describe Venting: * (include placement in tank and outside of aircraft dimensions, etc.)

13. Diagram compartment Numbering Order: *

14. Diagram and describe intervalometer or door triggering system: *

15. Diagram and describe Fill System: * (include location, crossflow arrangement, downloading capability, valves, dimensions, etc.)

16. Describe any differences between static and in-flight configuration that may affect testing and compensate for them.

17. Check for leaks: (interior or exterior)

18. Describe emergency dump system: *

19. Describe any special features of system:

20. Photograph airtanker, tanks and operating systems.

21. Fill airtanker using accurate meter and mark tank at volumes to be tested.

22. Fill levels and location of level to be tested: _____; _____; _____; _____;
    _____; _____; _____;

23. Record test matrix to be used:

24. For each test drop record

    a. Position of float in compartment.
        1. From top of compartment.
        2. From side and end of compartment.
        3. Distance from bottom of compartment to position of float at end of drop.
    b. Total vertical float travel.
    c. Drop configuration.
    d. Volume.
    e. Compartments tested.

*Provide measurements and/or drawing.

APPENDIX C
DATA ANALYSIS AND
VOLUME DISCHARGE ALGORITHM
FOR CENTRAL AIR SERVICES
DC-7 (TANKER 110)

The compartment dimensions and float travel measured during static testing of Central Air Services DC-7 tanker #110 were used to design an algorithm to calculate quantity discharged from the tank on a time basis for input to the PATSIM program. Door opening measurements are converted from analog data to angular units (degrees) as a function of time. Pressure measurements are converted to pounds/in² using a calibration constant for the individual transducer and recorded over the time base.

(Example Tank Cross Section)
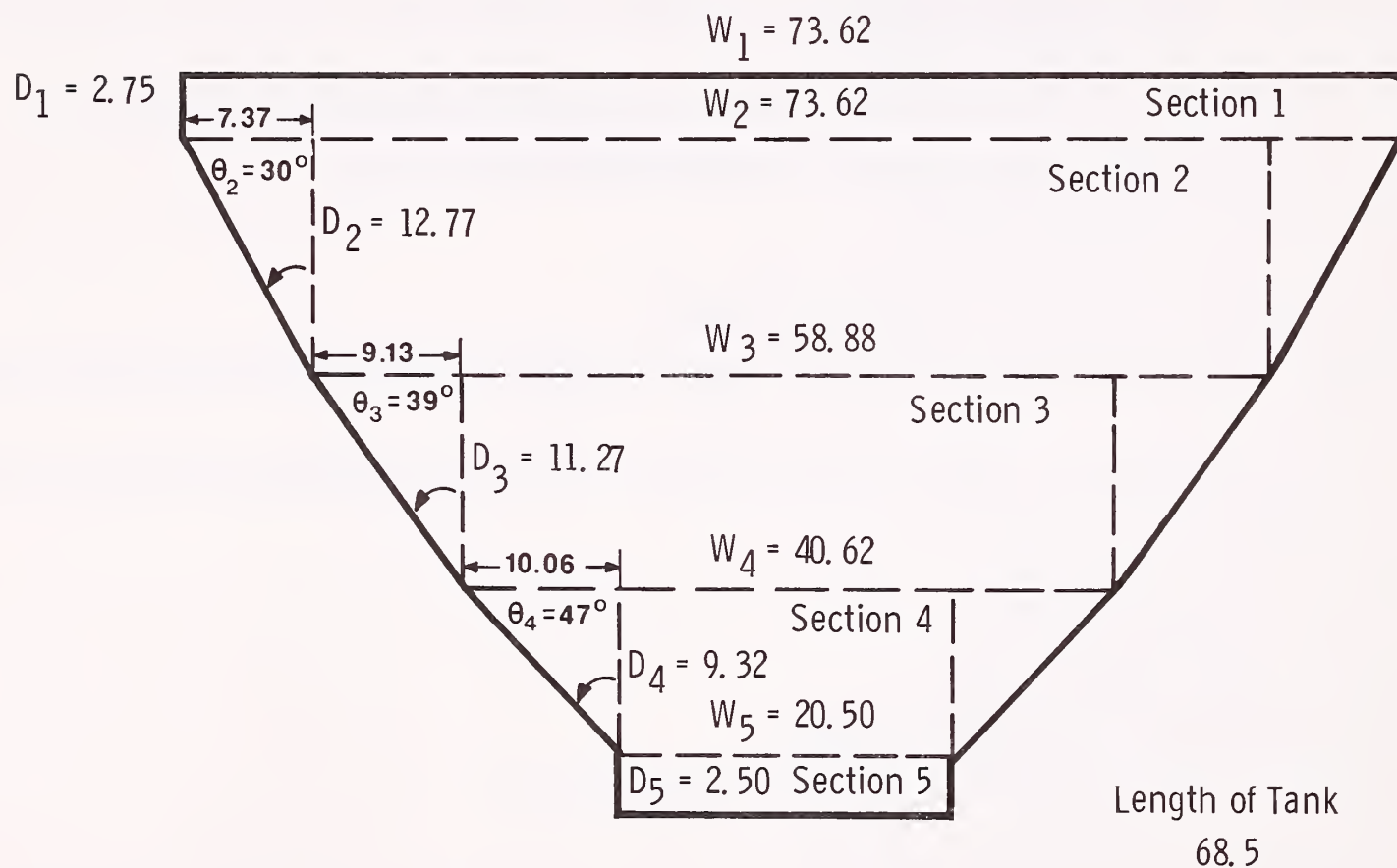
The sections are:

Section 1, top of tank to 2.75 down.
Section 2, 2.75 down to 15.52 down.
Section 3, 15.52 down to 26.79 down.
Section 4, 26.79 down to 36.11 down.
Section 5, 36.11 down to 38.61
(bottom of tank).

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Applying the method in figure 7.

Volume of Section 1 = $2.75 \times 68.5 \times 73.62 \times C$

($C = 4.33 \times 10^{-3}$ to convert inches to gallons or 16.38×10^{-3} to convert to liters.)

Volume for any float position i in Section 1:

$$= D1_i (73.62 \times 68.5)$$

where $D1_i$ is the distance the float has fallen within section i.

Volume $= 21.84\, D1_i$

For Section 2 with a triangular cross section

Volume = volume of rectangular portion − volume of triangular sections.

Applying the method in figure 7.

$\text{Volume}_2 = D2_i (73.62 \times 68.5 \times C) - 68.5 ((D2_i)^2 \times \text{Tan } 30°)\, C$

$\text{Volume}_2 = D2_i (21.84 - 0.17119 D2_i)$

Similarly:

Section 3, $\text{Volume}_3 = D3_i (17.725 - .2401\, D3_i)$

Section 4, $\text{Volume}_4 = D4_i (11.864 - .318\, D4_i)$

Section 5, $\text{Volume}_5 = 6.079\, D5_i$

An example of the analog data converted to appropriate units is given in table 3. Discharge data in this form are input to PATSIM to predict ground patterns for selected drop conditions. The flow rate is also calculated and is included in the technical data section of the airtanker performance guides.

Table 3.—Performance data for a single compartment release from Central Air Service DC-7 (Tanker #110)

Time	Distance above tank bottom	Volume discharged	Flow rate	Door open angle	Pressure	Section[1]
Sec	Inches	Gallons	Gal/sec	Degrees	Lb/in²	
0	35.8	0	0	0	0	
0.05	35.4	10	190	2.1	-0.01	
.10	34.8	21	213	4.8	- .02	
.15	34.1	36	237	8.5	- .04	
.20	33.2	55	275	13.5	- .07	2
.25	31.5	90	360	20.5	- .09	
.30	29.4	130	434	27.9	- .10	
.35	27.2	172	483	35.3	- .11	
.40	25.0	213	532	42.2	- .12	
.45	22.6	253	562	48.3	- .12	
.50	20.3	292	585	53.2	- .12	
.55	17.8	330	600	54.7	- .11	3
.60	15.5	363	605	68.6	- .11	
.65	13.2	392	603	76	- .10	
.70	10.9	420	599	80	- .10	
.75	8.7	442	590		- .09	
.80	6.7	460	575		- .09	4
.85						
.90						

[1]Fill level is below section 1. Mechanical restrictions required mounting the float end point above section 5.

Blakely, Aylmer D., Charles W. George, and Gregg M. Johnson.
   1982. Static testing to evaluate airtanker delivery performance. USDA For.
    Serv. Gen. Tech. Rep. INT-78, 17 p. Intermt. For. and Range Exp. Stn.,
    Ogden, Utah 84401.

   The USDA Forest Service in cooperation with Honeywell Corporation has
developed a series of Airtanker Performance Guides to provide predictions of
fire retardant ground distribution patterns from drop heights up to 500 feet
when dropped from a number of different airtankers. The performance guides
were produced using a Honeywell-developed simulation program and static
test data for each specific tank and gating system. This report describes a
method for collecting static test data and the analysis used in the develop-
ment of the airtanker performance guide. This is done so the performance of
any existing airtanker can be compared to the performance of any other
specific airtankers that have been static tested.

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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